PROJECT:		
TITLE: CATHODIC PROTECTION CALCULATION		

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I N D E X

1. INTRODUCTION

The cathodic protection system has been designed to protect the underground pipe

1.1 Codes and Standards

All the design and installation for cathodic protection system shall be in accordance with the latest edition of NACE standards (NACE RP 01-69). For materials and equipment, IEC code shall be considered.

Design Condition

The permissible maximum pipe to soil potential shall be -1.35 V (with reference electrode Cu/$CuSo_4$), -1.35 V is applied for the protection of both carbon steel and zinc coating.
Design condition include:

- Design Soil Temperature 30 °C
- Soil resistivity 3000-5000 Ohm-cm
- Period of Operation 20 years
- Backfill Coke Breeze or Graphite Powder
- Anode High Silicon Cast Iron
- Cable Non-Armoured XLPE/PVC or PVC/PVC

2. CURRENT REQUIREMENTS

For each protective item(s) a DC feeder, required current shall be calculated as follows:

$$I = dI * S \qquad [Eq. 1]$$

Where:

I = Required protection current (mA);
dI = Protection current density (mA/m^2);
S = Surface of item to be protected (m^2).

As a consequence of above calculation results, number of DC feeders and their rating shall be selected. DC feeder output current shall be suitably over-sized in order to allow spare current.

2.1 Protection current density

Considering design life, soil nature and applied coating types, protection current density values (dI) for design purposes are listed in Table 1.

Table 1 – Protection current density (dI)
According to NACE RP-01-76

Item	Anticorrosion Coating	Current Density (dI)
Steel piping	Poorly Coated Steel in Soil or Water	1 mA/m^2
Steel piping	Well Coated Steel in Soil or Water	0.03 mA/m^2
Steel piping	Very Well Coated Steel in Soil or Water	0.003 mA/m^2 or Less

2.2 Underground piping

Piping to be protected are Fire water (FW) pipes, Potable water (PW) pipes, Cooling water (CW) pipes and Sanitary drain pipes (SD). Characteristics of these lines have been extracted from piping department.

3. GROUND BED (GB) DESIGN

The positive ground bed system consists of a remote horizontal anode system. The design of GB shall be for maximum output current and for a 20 years period.
To obtain minimum no. of anodes in each GB, three cases shall be calculated and maximum of those shall be selected.

3.1 Resistance

- **Rv:** Resistance of Vertical Anode to Earth,
- **Ra:** Internal Anode Resistance,
- **Rvn:** Resistance to earth for n Vertical Anodes in Parallel,
- **Rca:** Anode Cable Tail Resistance,
- **Rg:** Ground Bed Resistance,
- **Rc:** Cable Resistance from Power Source to First Anode,
- **Rcp:** Coated Pipe Resistance.
- $\mathbf{R_{Total}}$**:** Total Resistance

- **R_{hn}:** Resistance to Earth for Horizontal Anodes in Parallel
- **R_{Pot}:** Resistance of Potentiometer
- **$R_{p/s}$:** Resistance of pipe to soil

Furthermore each ground bed shall be sized in respect of the maximum resistance (Rmax) of the relevant circuit, which is defined as the ratio between maximum output voltage and maximum output current of each DC feeder. The resistance of each circuit comprises ground bed to soil resistance, negative and positive circuits cables resistance.

3.1.1. Ground bed resistance

Single vertically laid anode resistance shall be calculated as follows (Dwight's formula):

$$Rv = Ra + Rca + \frac{0.00521 * \rho}{L}\left(2.3\log\frac{8*L}{d} - 1\right) \qquad \text{[Eq. 2]}$$

Where:

ρ**:** Soil resistivity (Ω * Cm);
L **:** Anode length (feet);
d **:** Anode diameter (feet).

Total "n" anode (constituted by two or more vertically laid anodes) resistance shall be calculated as follows:

$$Rv_n = \frac{Ra}{Na} + \frac{0.00521 * \rho}{L * Na}\left[2.3\log\left(\frac{8*L}{d}\right) - 1 + \frac{2*L}{g} * 2.3\log(0.656 * Na)\right]$$

[Eq. 3]

Where:

Na **:** Number of anodes
g **:** Spacing between anodes (feet)

Ground bed resistance (constituted by one or more ground bed) shall be calculated as follows (as measurable at Positive Bond Box):

$$\frac{1}{Rg} = \sum_{i=1}^{n} \frac{1}{Rvni} \qquad \text{[Eq. 4]}$$

Total resistance for CPS shall be calculated as follows:

$$R_{Total} = R_g + Rc + Rp/s + R_{Pot} \qquad \text{[Eq. 5]}$$

3.1.2. No. Of Anodes

No. of vertical anodes for a CPS shall be calculated (with the iteration methods) as follows:

$$N_a = \frac{1}{Rv_n} * \left(Ra + \frac{0.00521 * \rho}{L} * \left[2.3 \log \frac{8 * L}{d} - 1 + \frac{2 * L}{g} * 2.3 \log 0.656 * Na \right] \right) \quad \text{[Eq. 6]}$$

Where Rvn is the max permissible resistance of G.B. (2 Ohm for horizontal anode equal to 2.5 Ohm for vertical anode).
Because there is not any formula for multi horizontal anodes, first we shall calculate total resistance for vertical anodes and then convert it to horizontal anodes

After calculating number of anodes, final resistance shall be calculated with using [Eq. 3,4,5].

3.2. Current capacity

$Na = I/i_s$
Where:
i_s : Maximum allowed current for one anode

3.3. Consumption ratio

Na=(cr*t*I)/(m*f)
Where:
cr: consumption rate for one anode
t: total year
m: anode weight
f: utilization factor

4. TRANSFORMER / RECTIFIER SIZING

The magnitude of DC voltage required in the output of each TR/REC is product of the maximum current capacity and the total circuit resistance, thus:

$V_{DC} = I * R_{total}$ [Eq. 7]

Then:
$V_{DC\ fin} = V_{DC} * C_R$ [Eq. 8]
C_R: Accidental potential drop
$P_{REC} = V_{DC\ fin} * I$ [Eq. 9]
$P_{TR} = P_{REC} / EF$ [Eq. 10]

P_{REC}: DC power consumption (Output power of Rectifier)

P_{TR}: AC power consumption (Output power of Transformer)

$$V_{AC} = \frac{P_{TR}}{I} \quad \text{[Eq. 11]}$$

V_{AC}: Transformer secondary voltage.

5. CURRENT SPREAD

Ea = Em * Cos h (a*l) [Eq. 12]
a = √ (g * r)

Where:

Ea : change in potential at drain point (volt)
Em : change in potential at point " l" from the drain point (volt)
g : coating conductance in siemens/liner meter of pipe
r : pipe line resistance in ohm/liner meter of pipe
l : max. length of protective pipe

△ 6. PROJECT EXECUTE

All size and length of U/G Piping (FW, PW , CW &SD) is shown in civil under ground DWG. Total area of these lines with 25% contingency is about 1500 m².
So with use of [Eq. 1]:
I = 1 x 1500 = 1500 (mA) = 1.5 A
So, we assume one number rectifier of 5 A.
For as much as above current and considering assumed length of cable equal to 100 m and cross section of cable shall be considered 35 mm², space between anodes is 3 m, anode cable tail is 1.5 m with cross section of 16 mm² and average resistance of potentiometer is 0.5 ohm, De-rating factor for ground temp.=1.02
Thus:

R_c + Rpot = (0.0554*1.02)+0.5= 0.556 Ohm

No. Of anodes shall be calculated (with use of [Eq. 6]) as follows:

$$N_a = \frac{1}{2.5} * \left(0.106 + \frac{0.00521*5000}{5} * \left[2.3\log\left(\frac{8*5}{0.16}\right) - 1 + \frac{2*5}{10} * 2.3\log\left(0.656 * N_a\right) \right] \right)$$

Result of upper calculation for number of anode is 14 for every ground bed.

But according to **Current Capacity**:
Current capacity of each anode is: 9 A/sq. meters
So:

Na=5/2.15 =3 numbers

And according to **Consumption**:

Consumption rate for each anode is: 0.45 Kg/A. year
And unit weight of each anode is: 22.7 Kg
Utilization factor: 0.8

Na=(0.45*20*5)/(22.7*0.8) = 3 numbers

So we assume 15 numbers of anodes.

Again calculation for Rv_n is:

$$Rv_n = \frac{0.106}{15} + \frac{0.00521*5000}{5*15}\left[2.3\log(\frac{8*5}{0.16}) - 1 + \frac{2*5}{10}*2.3\log(0.656*15)\right]$$

Rv_n = 2.36 Ohm

Calculating factor for converting vertical ground bed to horizontal ground bed:

R_{vn}=2.36
r'=resistance of one vertical anode = 2.56 ohm
Na=number of anodes (15 no.)
r"= resistance of one horizontal anode=2.08 ohm
So:
Factor = R_{vn}/(r'/Na)
Factor = 2.36/(2.56/15)
Factor = 13.82
R_{hn} = (r"/Na)*factor
R_{hn} = (2.08/15)*13.82

R_{hn} = 1.91 ohm

So R_g is:

R_g = R_{hn} = 1.91 Ohm
R p/s = 1.35/5 = 0.27 Ohm
R_{total} is:
R_{total} = Rg + Rc+R pot + R p/s = 1.91 + 0.556 + 0.27= 2.736
$Vdc = Vdcb + (I * Rtotal) = 15.68V$
For Transformer and Rectifier sizing:
$V_{DC\ fin}$ = 15.68 *1.1 = 17.248 V
so we assume rectifier with 25 volts 5 amps.
P_{REC} = 25 * 5 = 125 W
With assume EF = 70 %:
P_{TR} = 125 / 0.70 = 180 W ~ 200 W

Calculating current spread:

Ea = 1.35 volt
Em = 0.85 volt
r = 2000 ohm/sq meter (after 20 years) & 10000 ohm/sq meter for new coating
r' = for worst case considering 2" pipe
p = 0.00000018 ohm.m for bare pipe
so:

L=9000 meter for new coating and 4000 meter after 20 years
so it can be seen that 1 CPS would be sufficient to create a satisfactory current spread after 20 years .